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Efficiency of Two High Elevation Camera Systems for Assessment of Insect-Caused Tree Mortality

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EFFICIENCY OF TWO HIGH ELEVATION CAMERA SYSTEMS FOR ASSESSMENT OF INSECT-CAUSED TREE MORTALITY

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ABSTRACT

Two medium-scale, high-resolution camera systems, flown by two U2 reconnaissance aircraft, were evaluated to determine their relative efficiency in quantifying bark beetle-killed timber in the Sierra Nevada. Color infrared imagery was obtained with an ITEK KA80A panoramic (optical bar) camera and an ACTON HR-732 (frame) camera. Large-scale (1:7,000) 9 x 9" underflight photography was also acquired to identify discreet areas of tree mortality and to provide a basis for ground truth. Map-referenced equal area grid overlays were used to compensate for scale changes and to permit accurate photo-to-map transfers.

Experienced photo interpreters compared the two formats on rear-projection viewers by estimating tree mortality and infestation levels. Bark beetle mortality was visible on both formats, but due to variation in color and resolution qualities, and the inability to distinguish new from old faders, consistent estimates at an acceptable level of precision could not be made. The best relationship was with stratification on the optical bar format, but the technique was too time-consuming to be operationally efficient. Although somewhat inconclusive, the overall characteristics and qualities of the optical bar format were judged to be superior to those of the frame camera.

INTRODUCTION

Surveys conducted in 1977 showed that multistage sampling techniques to quantify annual mortality caused by mountain pine beetle epidemics in lodgepole and ponderosa pine forests were feasible (Klein et al. 1978, Ciesla and Klein 1978). These surveys utilized aerial sketchmapping for stratification followed by large-scale color aerial photography in the first stage and ground surveys in the second stage. Although stratification was successful in minimizing variation of the whole population, the technique was judged relatively time-consuming, subjective, and highly variable between observers. Although stratification by aerial sketchmapping may be efficient on small areas, i.e., a million acres or less, it may not be operationally practical over large areas.

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One alternative to aerial sketchmapping is medium scale high-resolution photography taken from high altitudes.

There are two promising camera systems which utilize high-resolution color infrared (CIR) film at a theoretical nadir scale of 1:32,500 taken from a U2 reconnaissance aircraft at an altitude of 65,000 feet (MSL). The cameras are the ITEK, KA80A optical bar camera with a film format of 4½ x 50", and an ACTRON, HR-732, with a 9 x 18" format. Both cameras are equipped with a 24" focal length lens (Fig. 1). The KA80A optical bar system has recently been used to inventory dead timber on the Clearwater National Forest in Idaho (Duggan et al. 1977).

Plans were to use the KA80A optical bar system in conjunction with multistage damage surveys in Montana and South Dakota during 1978, but it was questioned whether an alternative system with more conventional format (9 x 18") such as the HR-732 might be equally effective. It was therefore decided that both formats should be compared prior to committing one system to an operational project.

The objectives of this evaluation were to determine (1) whether bark beetle killed conifers could be detected equally well from both camera formats, and (2) whether either format could be effectively used for stratification or final stage sampling.

METHODS

Description of Test Site

A test site 40 x 110 statute miles was established due east of Sacramento, California, running in a northwest-southeast direction from State Highway 88 in the south to slightly beyond Lake Oroville in the north (Fig. 2). The 40-mile wide swath encompassed portions of state and private lands and 4 National Forests: Lassen, Plumas, Tahoe, and Eldorado. The area has recently experienced a record 2-year drought and contains several hundred thousand moisture-stressed ponderosa pines that have been and are being attacked by bark beetles.

Cooperation

This pilot study was a cooperative undertaking between several agencies and organizations who provided the following services:

National Aeronautics and Space Administration (NASA) - acquired the high-elevation photography and provided duplicate copies of the film.

California Department of Forestry - provided field personnel for procurement of photo ground truth information.

USDA-Forest Service:

Nationwide Forestry Applications Program - funded and coordinated the U2 photography and assisted with the photo interpretation.

Special Mapping Center - generated equal area grid overlays.

Pacific Southwest Forest and Range Experiment Station - assisted in training of ground crews.

Forest Insect and Disease Management:

Region 2 - Provided viewing equipment and assisted with photo interpretation.

Region 3 - Provided viewing equipment and assisted with photo interpretation.

Region 5 - Took the large scale (1:7,000) CIR underflight photography.

Methods Application Group - Planned, coordinated, and reported results. Also provided interpretation equipment and facilities, and assisted ground crews.

Aerial Photography

Three photo formats, optical bar, 9 x 18", and 9 x 9" large-scale underfights were acquired. The large-scale photography served to locate and delimit tree mortality and provide a basis for collecting ground truth.

The high-altitude aerial photography was taken on March 27 by two NASA U2 aircraft, based at Moffett Field, California. Both aircraft flew at 65,000' (19,800 M), 31 minutes apart; the first run, with optical bar equipment, began at 20:36 (GMT). The actual runs for the optical bar and 9 x 18" camera aircraft required 16 and 26 minutes, respectively. The KA80A camera containing Aerochrome infrared SO-131 was unfiltered while the HR-723 camera with SO-127 was equipped with a CC.30B filter[2].

The aircraft with the optical bar camera flew a single swath 110 statute miles long, while the aircraft containing the 9 x 18" camera configuration flew 2 parallel swaths (20% sidelap) approximately 72 miles long down the center of the optical bar swath (Fig. 2).

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2 The platform consisted of a bank of 3 synchronized HR-732 cameras, one with Aerochrome infrared WO-127, the second with aerial color SO-242 with an HF3 filter, and the third with Panatomic-X3400 with a Wratan filter. Comparison of the 3 films will be made by NFAP.

Large-scale sample photography was taken April 12. CIR stereo pairs at a scale of ca. 1:7,000 were taken at 1½-mile intervals along four parallel flight lines (Fig. 2). The film was processed and delivered to MAG in Davis on April 17.

The optical bar film was processed and duplicates made within a week, but due to other priorities, NASA did not process the 9 x 18" photography until April 17. The film was delivered to MAG in Davis, California, on April 18. Indexing began the next day.

Indexing

Principal points of the U2 photography and effective stereo area of the 9 x 9" photography was marked on a 1:250,000 topographic map. To facilitate handling, placement of equal area grid overlays, and viewing, the U2 frames were cut from their respective rolls. A cross-indexing system showing the location of each format in respect to each other was prepared (Fig. 3).

Equal Area Grid Overlays

Due to the large decrease in scale from nadir to the edges, the U2 photography was partially resectioned to permit transfer of data from the photos to maps. These map-referenced equal-area grid overlays were produced at the Forest Service Special Mapping Center (Fig. 4). This technique, using conventional photographic resection methods, compensated for camera and altitudinal positional errors at time of exposure. Displacement due to differences in terrain elevation were compensated for by use of Defense Mapping Agency Topographic Command (DMATC) digital terrain data.

Locating Tree Mortality

The 9 x 9" large-scale sample photography was closely examined for recent tree mortality (faders). Only those photos on each of the 4 flight lines and parallel to the swath covered by the 9 x 18" photography were examined. Of some 300 stereo pairs examined, only 20 contained a sufficient number of faders that were in stereo and worthy of ground checking[3]. Equal-area grid overlays were produced for the U2 frames containing ground truth plots. The first set arrived in Davis on May 6. Additional sets arrived on May 20 and 24.

Once received, the overlays were attached to their corresponding frames. The boundaries of the 40-acre blocks printed on the transparent overlays and containing, as nearly as possible, the faded trees, were then visually transferred to the large-scale photography.

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[3] Ground checking of 15 of these plots showed an average density of 1.6 red-topped or fading trees per acre.

Ground Truth

Ground truth surveys were conducted during the period May 15-26. Crews consisting of 2 or more persons were given a one-day training session prior to their plot assignments. The 40-acre plots were located by use of small-scale maps and the 9 x 18" CIR photography. Once on the plot, plot corners and boundaries and faded trees were located by stereoscopic viewing of the 9 x 9" large-scale photography. All trees identified on the photos as "faders" were counted and their diameters (2-inch class) and crown condition were recorded (Fig. 5). Practically all of the affected trees were ponderosa pines topkilled by Ips engraver beetles, Ips paraconfusus, with occasional secondary infestations of the western pine beetle, Dendroctonus brevicomis, or to a lesser extent, flat-headed borers. Salvage of infested trees had begun in some plots, but their stumps were identified on the photos. In other plots, however, logging had removed green trees as well as dead; consequently, some of these had to be dropped from the evaluation.

An inherent and obvious problem with optical bar photography and its unconventional format was its questionable use in the field. There was no method or device available for viewing it effectively in the woods. This limitation was partly overcome by the development of a portable, lightweight, solar-illuminated stereo viewer (Fig. 6). Additional features are that it permits variable magnification (2-4x), and most important, individual frames can be left intact. The instrument will continue to be evaluated and improved.

Photo Interpretation

The 3 photo interpreters were required to independently (1) stratify a block of about 100 40-acre grid cells in each U2 frame, and (2) make individual tree counts from within 20 randomly-selected 40-acre blocks within each stratification group on both U2 formats (Fig. 4). These groups occurred between nadir and $\pm$ 24° on the optical bar frames. The interpreters, of course, did not know which plots contained the ground truth data. The optical bar and 9 x 18" frames were viewed and interpreted on specially adapted Vantage (Realist) Model 3352 rear projection microfilm readers. Orientation and plot location was accomplished by a floating cursor-pointer attached to the reader carrier and moved across a facsimile grid attached to a Masonite board at the base of the reader (Fig. 6). Once oriented, this enabled the interpreter to move the pointer to any position on the fascimile and view the identical area on the screen. Special extensions were placed on the sides of the carrier to accommodate the optical bar transparencies.

Analysis of Data

The analysis was made on the basis of a comparison of counts made from 15 identical 40-acre plots common to all photographic formats--optical bar, 9 x 18", and 9 x 9". Linear regression equations and a coefficient of determination (R^2) was calculated for each interpreter and for each exercise. Initially, it was planned to determine whether

there was a degradation in interpreter accuracy on the optical bar format between plots closest to nadir, ca. ± 12°, and those farther away, ca. ± 46°. This was not done for there was insufficient tree mortality on the 9 x 9" photography along the 2 outermost flight lines to permit a valid comparison.

Stratification

In a stratification exercise the important factor is not so much accuracy of individual tree counts but an ability to separate the area into 2 or more consistent intensity classes. In an operational mode, for example, during an aerial photographic survey where an estimate of the population total is computed from a preliminary survey, strata divisions would be assigned, and each stratum sampled independently. In the case of extensive bark beetle surveys, only 2 strata would be used--light and heavy. The actual strata division might be based on some prior knowledge of the population variance, combined with other non-statistical factors such as topography, ownership, land use, or economics.

In this exercise, stratification consistency was determined by computing the mean tree count per plot for each interpreter, determining the midpoint or mean, and computing the number of plots that fell on either side of the mean.

RESULTS

The results of this study are clouded by the fact that there were unanticipated differences in the color and resolution qualities of each format. The color balance of the optical bar film can best be described as "subdued" while the color balance of the 9 x 18" film was considerably "hotter", meaning that the colors were brighter and there was greater contrast between the affected and unaffected trees. The subdued nature of the SO-131 optical bar transparencies was due to low contrast and a dominant cyan cast. Although no filter was used on the KA80A and a color compensating .30B filter was used on the HR-732, this should not have been an important factor since the film itself contains a minus blue emulsion layer. However, it was noted that the HR-732 film was slightly under-exposed, resulting in increased exposure and degradation of resolution during the duplication process, thus reducing its quality rating from excellent to good[4]. A comparison of the 2 formats is shown in Figure 8.

Another factor affecting the visual interpretation was the condition of the faded trees at the time of photography. The trees or portions of trees that were faded in March were attacked last summer by the western pine beetle, or late fall by *Ips* spp. (probably *Ips paraconfusus*). The crown condition of western pine beetle killed trees was such that they

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[4] Flight Summary Report 1118. NASA Ames Research Center, Moffett Field, California. March 27, 1978. 3 pp.

could easily have been judged as either an "old kill" or "new fader", while Ips-caused topkill, regardless of the extent, was noted as a new fader. In many cases, the differences were so subtle that they could not be detected consistently on large-scale photography[5], much less on the smaller scale U2 photography.

Photo Interpretation

The results of both exercises--actual tree counts and stratification--are shown in Tables 1 and 2. The coefficients of determination (R^2) ranged widely between interpreters, formats, and exercises. Clearly, in regard to accurate or consistent tree enumeration, neither format had the clear advantage. The exceptionally high R^2 value (0.94) for one interpreter in the stratification exercise may have occured solely by chance. It was the consensus of the interpreters that the relatively poor correlations were due to the lack of color contrast in the optical bar imagery and the relatively poor resolution of the 9 x 18" transparencies. The resolution qualities of the optical bar imagery were excellent but this did not offset the lack of color contrast.

Stratification

Mean photo count was, on the average, less than half the ground count, and the stratification ranges varied between interpreters. Combined plot estimates were evenly distributed on both sides of the mean, however (Table 3). In an operational mode, individual interpreter estimates would also be pooled.

In an operational mode, one interpreter would be able to interpret ca. 28,000 acres in one day using these same stratification techniques. This corresponds to one optical bar frame $\pm$ 36°. By comparison, an experienced aerial sketchmapper, flying a contour pattern as is common in mountainous terrain, would be able to sketchmap (4 hours flying) and stratify (4 hours office) ca. 250,000 acres in one day[6].

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5 An experienced photo interpreter counting the faders in the large-scale (1:7,000) sample photography with an Old Delph stereoscope had an R^2 value of 0.58.

6 This figure is somewhat variable, and depends upon airspeed, reconnaissance altitude, pattern of flight, and observer experience.

Table 1. Comparison of photo-to-ground counts on optical bar and 9 x 18 aerial photography by three photo interpreters.

Plot No.	Ground Count	INTERPRETER B				INTERPRETER D				INTERPRETER W			
		OPTICAL BAR		9 x 18		OPTICAL BAR		9 x 18		OPTICAL BAR		9 x 18	
		Tree Count	Stratification	Tree Count	Stratification	Tree Count	Stratification	Tree Count	Stratification	Tree Count	Stratification	Tree Count	Stratification
175	80	9	0	20	20	5	5	39	15	27	12	32	20
167	98	83	75	41	30	78	100	49	50	125	55	100	30
167	63	43	15	11	5	49	50	5	5	70	45	22	7
250	32	46	40	19	15	16	15	14	15	16	10	14	8
141	15	6	5	1	0	0	0	2	5	0	0	1	1
141	25	0	0	0	0	3	0	5	5	2	2	0	0
137	24	10	10	14	10	23	20	16	10	12	5	15	10
135	65	60	25	61	50	61	50	86	100	68	50	92	110
135	57	44	20	29	20	57	50	45	40	51	30	34	15
130	16	2	0	12	10	0	0	5	2	11	5	11	5
130	64	25	15	48	35	14	10	35	25	38	14	48	35
261	42	7	5	14	10	9	5	8	5	12	10	13	6
261	50	24	20	46	35	42	40	49	50	38	20	10	12
268	310	55	*	64	60	*	*	*	*	125	200	58	40
122	56	145	75	20	15	75	145	74	45	24	10	26	15
TOTAL	997	559	305	400	315	432	490	432	372	619	468	476	314

* Did not complete.

Table 2. Summary of regression estimators for photo-ground comparisons by 3 photo interpreters.

	OPTICAL BAR						9 x 18"					
	PHOTO COUNT			STRATIFICATION			PHOTO COUNT			STRATIFICATION		
Interpreter	$\bar{x}$	R^2	Sy. x	$\bar{x}$	R^2	Sy. x	$\bar{x}$	R^2	Sy. x	$\bar{x}$	R^2	Sy. x
B	37.26	0.08	71.16	21.79	0.25	22.24	26.67	0.43	56.19	21.0	0.54	50.33
D	30.86	0.41	19.79	35.00	0.29	21.74	30.86	0.38	20.21	26.57	0.28	21.82
W	41.27	0.59	47.43	31.20	0.94	17.99	31.73	0.23	65.25	20.93	0.11	70.01

Table 3. Comparison of plot means by stratification and the number of plots on both sides of the mean.

		OPTICAL BAR				9 x 18"			
	Mean ground count for all plots	ALL PLOTS				ALL PLOTS			
P.I.		Mean photo count	Mid-point*	No. of plots from midpoint**		Mean photo count	Mid-point*	No. of plots from midpoint**	
B	66.4	21.7	10.8	6	8	21.0	10.5	6	9
D	66.4	35.0	17.0	7	7	26.6	13.3	6	8
W	66.4	31.2	15.6	9	6	20.9	10.5	7	8
Average	66.4	29.3	14.5	7.3	7	22.8	11.4	6.3	8.3

* Midpoint is the mean of the mean photo count; for example, 21.7÷2 = 10.8

** Although there was a total of 15 plots, two interpreters did only 14 plots each.

Forward Overlap

Previous experience with optical bar photography indicated less than 60 percent forward lap. A sample of 15 optical bar overlapping pairs and ten 9 x 18" pairs were systematically selected and their forward lap at nadir measured and subjected to an analysis of variance.

The results of the forward lap measurements at nadir for the U2 formats showed 50 percent ($s = \pm 1.34$) forward lap for the optical bar photography and 68 percent ($s = \pm 1.14$) for the 9 x 18" photography. With the optical bar format, however, forward lap increases from nadir and with decrease in scale.

CONCLUSIONS

1. Techniques were developed for indexing and cross indexing both high elevation formats.

2. Methods were developed for viewing and interpreting the U2 photography monoscopically using conventional, but slightly modified, microfilm readers. The optical bar film could be viewed without cutting lengthwise but the 9 x 18" film had to be cut.

3. A lightweight, portable, solar-illuminated stereoscope was developed for viewing and interpreting the optical bar film in the field.

4. Equal area map referenced grid overlays were generated for individual optical bar and 9 x 18" frames. The fit between any two frames of corresponding scenes of the optical bar and 9 x 18" formats and between successive overlapping frames of the same format, was excellent. The only difficulty was in the manual fitting of the overlay to the transparencies. In some instances, the reference points could not be exactly matched. In a productive mode, it would be possible to produce approximately 50 individual grid overlays a week[7].

5. No difference was found in tree count accuracy or stratification between the U2 formats. The surprisingly good R^2 (0.94) for one interpreter in the stratification exercise with the optical bar photography was probably by chance.

6. Individual tree counts from all 3 formats--optical bar, 9 x 18", and 9 x 9" large-scale--could not be made with an acceptable level of confidence.

7. Either U2 format could be used in a stratification exercise, but the optical bar data, although cursory, indicated slightly better results. Using the techniques described here, an interpreter could stratify some 28,000 acres in one day. By contrast, an experienced aerial sketchmapper can map and stratify approximately 250,000 acres in approximately the same time.

RECOMMENDATIONS

Although the results of this study, as set forth by the objectives, are inconclusive, it was the consensus of those working on this evaluation--photo interpreters, technicians, and these writers--that the optical bar format was, in most aspects, superior to the 9 x 18" photography. The advantage of the panoramic format over the 9 x 18" format was that (1) it had superior resolution, (2) was better adapted to a standard microfilm reader, and (3) it covered more area with less film. It was equally felt that with a better color balance and less variable tree fading conditions, higher R^2 values for tree counting and stratification would result.

Plans for 1978 should be to procure optical bar photography on portions of the Beaverhead, Gallatin, Flathead, and Lewis and Clark National Forests in Montana, and the Black Hills National Forest in South Dakota and Wyoming. With the exception of the Flathead National Forest, these photo flights will be made in conjunction with conventional multistage bark beetle damage surveys. The first photo flight will be on the Gallatin-Beaverhead mountain pine beetle infestation during which the following procedures will be attempted:

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[7] Personal communication with Richard Liston, Special Mapping Center.

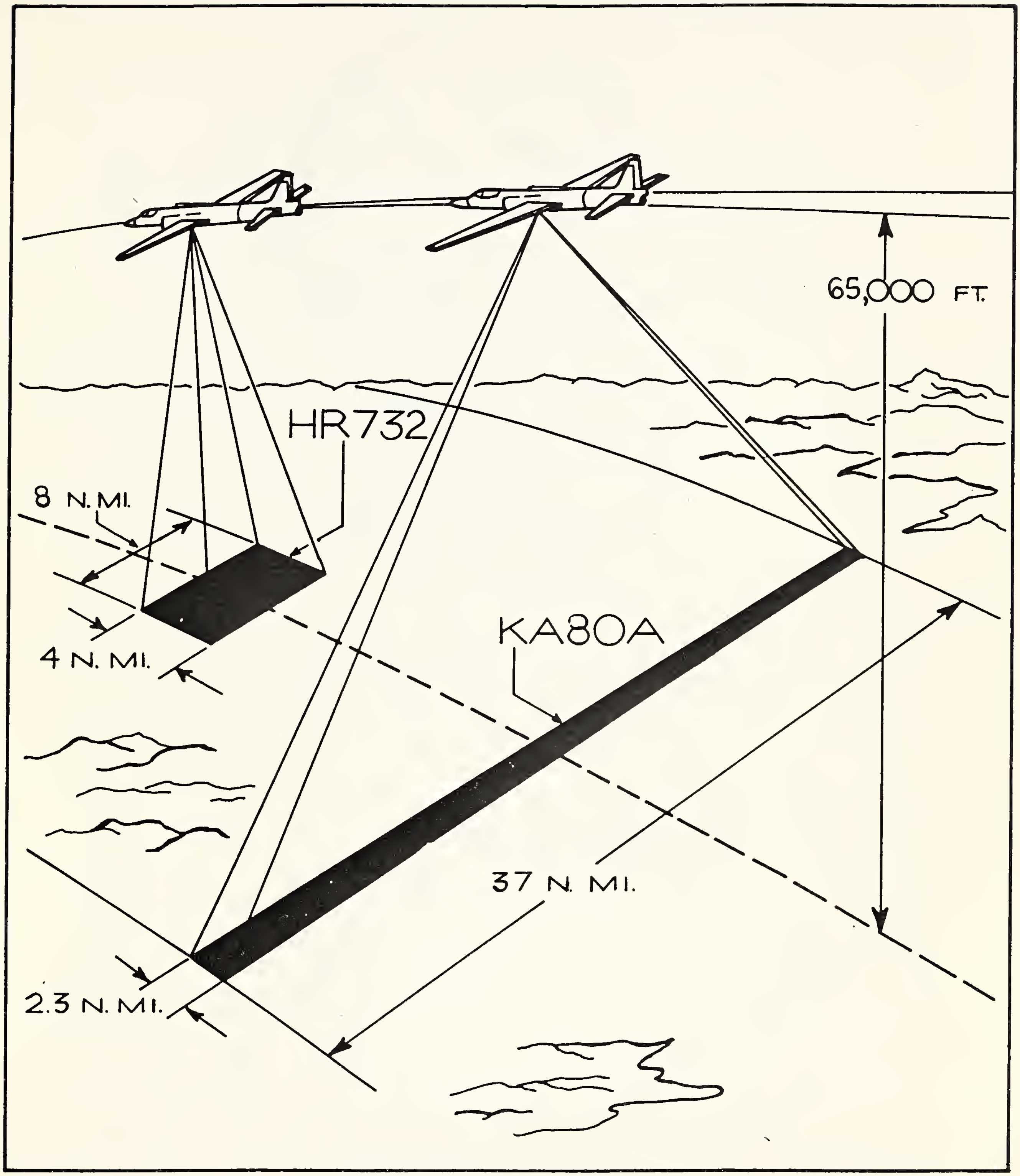

Figure 1. Relative ground coverage by two high altitude camera systems compared in this evaluation.

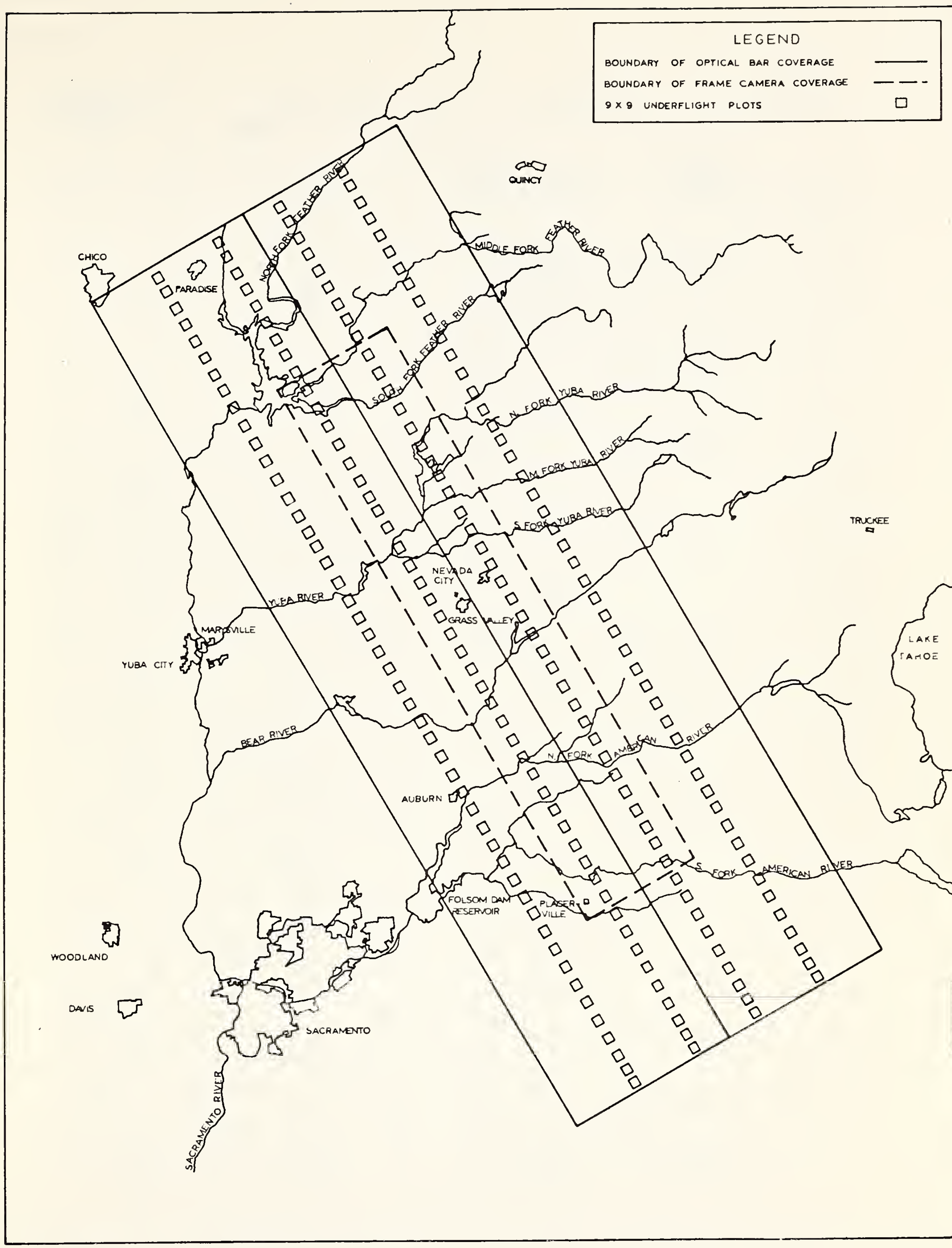

Figure 2. Aerial photographic acreage obtained of the Northern California test site with 3 camera systems.

OPTICAL BAR	9 X 18 WEST	EAST	9 X 9 A	B	C	D	REMARKS
			O.B.			O.B.	
18			15/16	183/184		374/375	
20	2	94	17/18	181/182	211/212	372/373	
21	3			179/180			
22	3	93	19/20		213/214	370/371	
23	4			177/178			
24	4	92	21/22		215/216	368/369	
25	5			175/176			
26	6	90	23/24		217/218	366/367	
27	7			173/174			
28	8	89	25/26		219/220	364/365	
29	9			171/172			
30	10	87	27/28		221/222	362/363	
31	10			169/170			
32	11/12	86	29/30		223/224	360/361	
33	11			167/168			
34	12	85	31/32		225/226	358/359	
35	13			165/166			
36	13/14/15	83	33/34		227/228		
37	15			163/164		356/357	
38	15	82	35/36		229/230	354/355	
39	16			161/162			
40	17	80	37/-40		231/232		
41	17	79		159/160		352/353	
42	18/19	78	41/42		233/234		
43	19			157/158		350/351	
44	19/20	77	43/44		235/236		
45	20			155/156		348/349	
46	21/22	76	45/46		237/238		
47	22			153/154		346/347	
48	22/23	74	47/48		239/240		
49	23			151/152		344/345	

Figure 3. Form used to cross index the three photographic formats. The numbers are the actual frame numbers.

CALIFORNIA U2 PILOT PROJECT

PHOTO NOS. : OB 72 , 9 X 18 58 , 9 X 9 129/130

CREW GNAS, SEAMOUNT, HUNT ; DATE 5/24/78

APPROXIMATE TIMES: TO PLOT 1/2 HOUR ; ON PLOT 2 1/2 HOURS

DBH CLASS[1]	DAMAGE CATEGORY[2] 1	2	3	4		REMARKS
4			3	5	8	SITE 3-4 THE AREAS CIRCLED IN RED ON THE PHOTO WERE LOGGED AFTER THIS PICTURE WAS TAKEN NOTICE THE FALLING CREWS ON THE ROAD AND THE SKID CAT MOVING INTO THE BRUSH
6				4	4	
8				11	11	
10		1		8	9	
12				15	15	
14	1		1	6	8	
16		1		2	3	
18	1			3	4	
20				1	1	
>20				1	1 / 64	22

1 TWO INCH DIAMETER CLASSES (I.E. 10 = 9.1 TO 11.0)

2 DAMAGE CATEGORIES: 1, TOP 1/3 CROWN FADED; 2, 2/3 OF CROWN FADED; 3, ENTIRE CROWN FADED; 4, ENTIRE CROWN FADED WITH BOLE ATTACKS

Figure 5. Ground truth tally form.

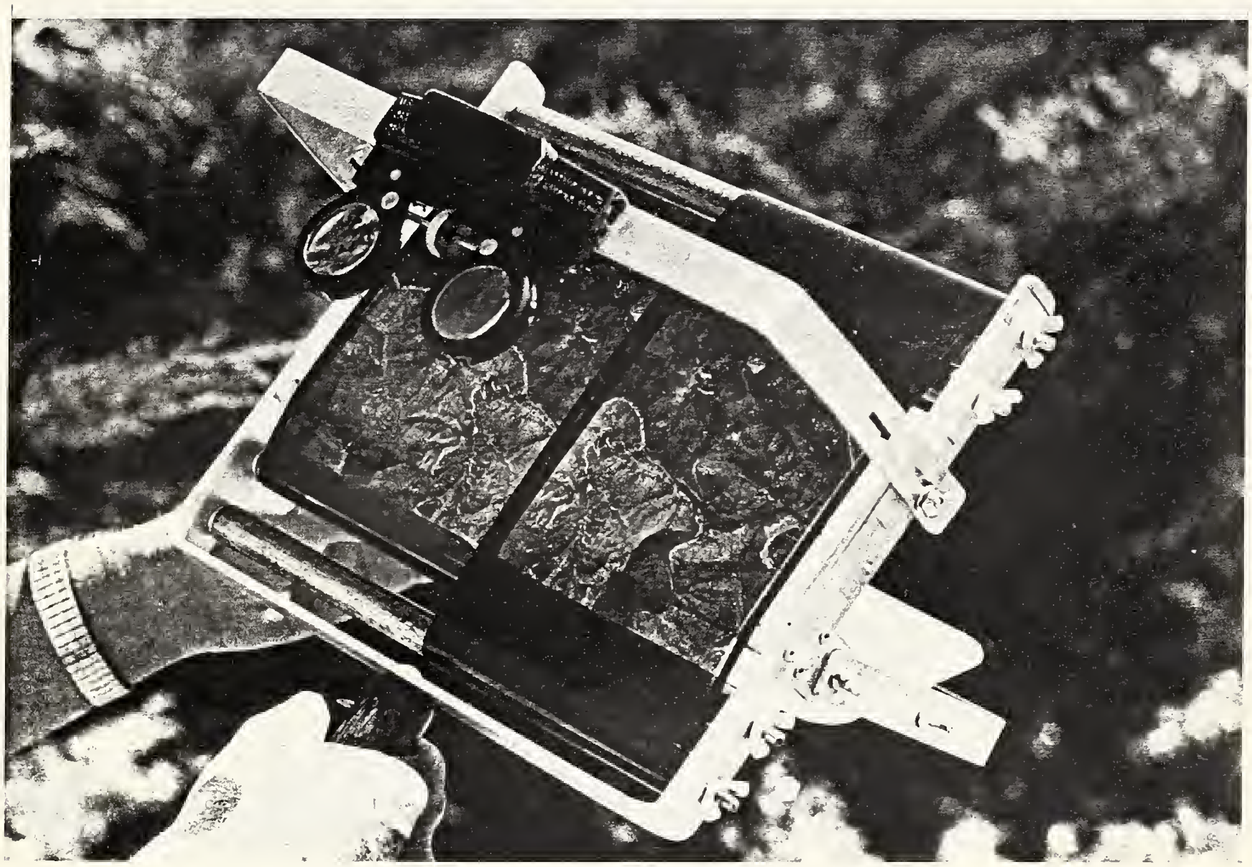

Figure 6. Portable stereoscope for viewing optical bar photography. Light is reflected through the translucent surface by an adjustable solar reflector.

Figure 7. Photo interpreter viewing U2 imagery (9 x 18") with microfilm reader. The equal-area grid facsimile at base of reader permits photo orientation and specific plot location.

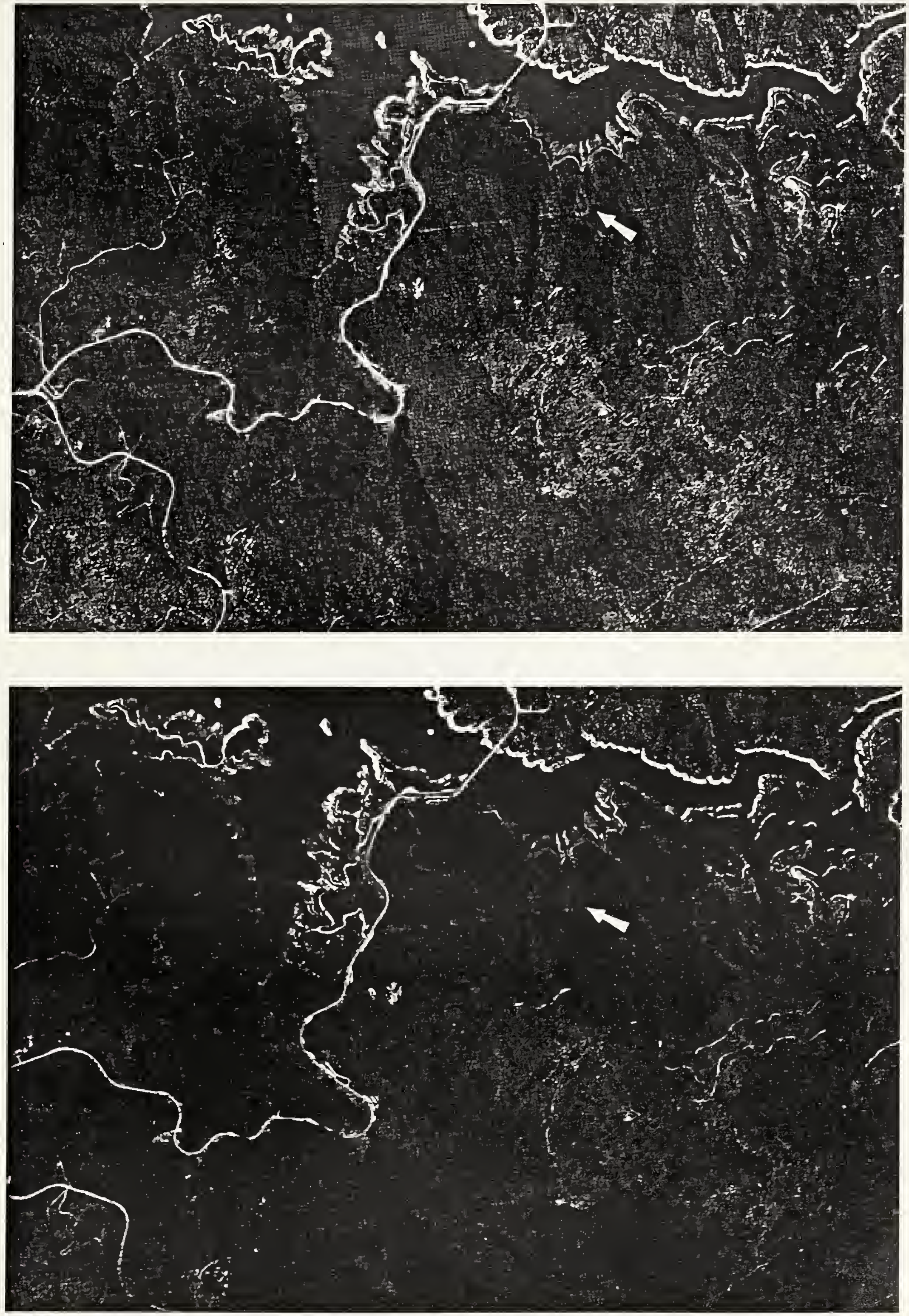

Figure 8. Cibachrome prints from second generation positive transparencies of similar areas of optical bar (top), and 9 x 18" (bottom) high elevation photography. The arrows point to groups of faded ponderosa pine which can best be seen by magnification. The center of the optical bar photograph (top) is ca. 21° from nadir, which accounts for its smaller scale.